NUMERICAL SIMULATION OF AERODYNAMIC FORCES ON A COMPLEX VEHICLE FLYING AT EARTH ORBIT

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ABSTRACT

Analysis of the trajectory and attitude control of an earth orbital flying vehicle requires the best knowledge of aerodynamic forces on the vehicle. A detail analysis of these forces must be carried out and incorporated into the vehicle design.

Depending on the governing physical phenomena, the fluid flow can be divided into three general categories. The first is the ordinary regime of continuum flow, in which intermolecular collisions are the important phenomena. The second is called the ``transitional regime", in which molecule-molecule and molecule-surface interactions are of equal importance. The third is the free molecule flow, in which molecule-surface interactions are the governing phenomena. The flow regime for a particular problem is determined by the Knudsen number, Kn, which is defined as a ratio of the molecule mean free path and the vehicle characteristic length. In general, if the Knudsen number is less than 0.01, the flow is in continuum regime; if the Knudsen number is between 0.01 and 10, the flow is in transitional regime; and if the Knudsen number is greater than 10, the flow is in free molecule flow regime. The computation of the aerodynamic forces on the orbital flying vehicle is a typical free molecule flow problem, because the molecule mean free path is much larger than the vehicle length at that altitude.

For the free molecule flow, exact solutions of the aerodynamic forces can be obtained for a flat plate and the cylinder. For the most configurations, in particular for really flying vehicles, the numerical solution is only a valuable approach. In early investigations, the complex vehicle was analyzed by treating each composite part of the vehicle as a separate simple body. It means that the complex vehicle is resolved into a combination of sub-shapes consisting of the available sub-shape types, such as rectangular plate, triangular plate, sphere, cone and cylinder. In order to calculate aerodynamic forces, two different coordinate systems have to be employed. The composite coordinate system is used for the vehicle, and a local individual coordinate system is used for each sub-shape.

In this study, the computer cord of general orbital aerodynamic forces on complex vehicle was developed. Based on methodology of the finite element method, the surface of the vehicle is replaced by a large number of small plane triangles, and one fixed coordinate system is used. Therefore, numerical accuracy of the solutions can be significantly improved, and the computer implementation is also greatly simplified. Validation tests were conducted for the flat plate, square cubic and other complex geometry. Comparison with available solutions shows that this computer cord is capable of predicting aerodynamic forces on complex vehicle flying at earth orbit with an angle of attack or rolling angle accurately.